STRUCTURE AND TRANSFORMATION OF MATTER

A basic understanding of matter is essential to the conceptual development of other big ideas in science. In the elementary years of conceptual development, students will be studying properties of matter and physical changes of matter at the macro level through direct observations, forming the foundation for subsequent learning. During the middle years, physical and chemical changes in matter are observed, and students begin to relate these changes to the smaller constituents of matter—namely, atoms and molecules. By high school, students will be dealing with evidence from both direct and indirect observations (microscopic level and smaller) to consider theories related to change and conservation of matter. The use of models (and an understanding of their scales and limitations) is an effective means of learning about the structure of matter. Looking for patterns in properties is also critical to comparing and explaining differences in matter.

High School

Physical Science

SC-HS-1.1.1 Students will classify or make generalizations about elements from data of observed patterns in atomic structure and/or position on the periodic table.

The periodic table is a consequence of the repeating pattern of outermost electrons. DOK 2

SC-HS-1.1.2 Students will understand that the atom's nucleus is composed of protons and neutrons that are much more massive than electrons. When an element has atoms that differ in the number of neutrons, these atoms are called different isotopes of the element.

SC-HS-1.1.3 Students will understand that solids, liquids, and gases differ in the distances between molecules or atoms and therefore the energy that binds them together. In solids, the structure is nearly rigid; in liquids, molecules or atoms move around each other but do not move apart; and in gases, molecules or atoms move almost independently of each other and are relatively far apart.

SC-HS-1.1.4 Students will understand that in conducting materials, electrons flow easily; whereas, in insulating materials, they can hardly flow at all. Semiconducting materials have intermediate behavior. At low temperatures, some materials become superconductors and offer no resistance to the flow of electrons.

SC-HS-1.1.5 Students will explain the role of intermolecular or intramolecular interactions on the physical properties (solubility, density, polarity, boiling/melting points) of compounds.

The physical properties of compounds reflect the nature of the interactions among molecules. These interactions are determined by the structure of the molecule including the constituent atoms. DOK 2

SC-HS-1.1.6 Students will • **identify variables that affect reaction rates;** • **predict effects of changes in variables (concentration, temperature, properties of reactants, surface area, and catalysts) based on evidence/data from chemical reactions** Rates of chemical reactions vary. Reaction rates depend on concentration, temperature, and properties of reactants. Catalysts speed up chemical reactions. DOK 3
SC-HS-1.1.7 Students will • **construct diagrams to illustrate ionic or covalent bonding.** • **predict compound formation and bond type as either ionic or covalent (polar, nonpolar).** Bonds between atoms are created when outer electrons are paired by being transferred (ionic) or shared (covalent). A compound is formed when two or more kinds of atoms bind together chemically. DOK 2
SC-HS-1.1 8 Students will • **explain the importance of chemical reactions in a real-world context.** • **justify conclusions using evidence/data from chemical reactions.** Chemical reactions (e.g., acids and bases, oxidation, rusting, tarnishing) occur all around us and in every cell in our bodies. These reactions may release or absorb energy. DOK 3

MOTION AND FORCES

Whether observing airplanes, baseballs, planets, or people, the motion of all bodies is governed by the same basic rules. In the elementary years of conceptual development, students need multiple opportunities to experience, observe, and describe (in words and pictures) motion, including factors (i.e., pushing and pulling) that affect motion. At the middle level, qualitative descriptions of the relationship between forces and motion will provide the foundation for quantitative applications of Newton's Laws. These ideas are more fully developed at the high school level along with the use of models to support evidence of motion in abstract or invisible phenomena such as electromagnetism.

High School

Physical Science

SC-HS-1.2.1 Students will

- **select or construct accurate and appropriate representations for motion (visual, graphical, and mathematical).**
- **defend conclusions/explanations about the motion of objects and real-life phenomena from evidence/data.**

Objects change their motion only when a net force is applied. Newton's Laws of motion are used to describe the effects of forces on the motion of objects. Conservation of mechanical energy and conservation of momentum may also be used to predict motion. DOK 3

SC-HS-1.2.2 Students will

- **explain the relationship between electricity and magnetism.**
- **propose solutions to real life problems involving electromagnetism.**

Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces or "fields", and moving magnets produce electric forces or "fields". This idea underlies the operation of electric motors and generators. DOK 3

SC-HS-1.2.3 Students will understand that the electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel.

THE EARTH AND THE UNIVERSE

The Earth system is in a constant state of change. These changes affect life on earth in many ways. Development of conceptual understandings about processes that shape the Earth begin at the elementary level with understanding *what* Earth materials are and that change occurs. At the middle level, students investigate *how* these changes occur. Finally, at the high school level, most of the emphasis is on *why* these changes occur. An understanding of systems and their interacting components will enable students to evaluate supporting theories of earth changes. At the heart of elementary students' initial understanding of the Earth's place in the universe is direct observation of the earth-sun-moon system. Students can derive important conceptual understandings about the system as they describe interactions resulting in shadows, moon phases, and day and night. The use of models and observance of patterns to explain common phenomena is essential to building a conceptual foundation and supporting ideas with evidence at all levels. In middle school, students begin to look beyond what can be directly observed as they explore the earth-sun-moon system, as well as the rest of our solar system, employing the concept of scale within their models. Patterns play an important role as students seek to develop a conceptual understanding of gravity in their world and in the universe. High school is the time to bring all of the ideas together to look at the universe as a whole. Students will use evidence to evaluate and analyze theories related to the origin of the universe and all components of the universe.

High School

Earth/Space Science

SC-HS-2.3.1 Students will

- **explain phenomena (falling objects, planetary motion, satellite motion) related to gravity;**
- **describe the factors that affect gravitational force**

Gravity is a universal force that each mass exerts on every other mass. DOK 3

SC-HS-2.3.2 Students will

- **describe the current scientific theory of the formation of the universe (Big Bang) and its evidence;**
- **explain the role of gravity in the formation of the universe and it's components.**

The big bang theory and observational measurements that support it place the origin of the universe at a time between 10 and 20 billion years ago, when the universe began in a hot dense state. According to this theory, the universe has been expanding since then. Early in the history of the universe, the first atoms to form were mainly hydrogen and helium. Over time, these elements clump together by gravitational attraction to form trillions of stars**.** DOK 2

SC-HS-2.3.3 Students will explain the origin of the heavy elements in planetary objects (planets, stars).

Some stars explode at the end of their lives, and the heavy elements they have created are blasted out into space to form the next generation of stars and planets. DOK 2

SC-HS-2.3.4 Students will understand that stars have life cycles of birth through death that are analogous to those of living organisms. During their lifetimes, stars generate energy from nuclear fusion reactions that create successively heavier chemical elements.

SC-HS-2.3.5 Students will

- **explain the difference between fission (alpha and beta decay) and fusion**
- **identify the relationship between nuclear reactions and energy**

Nuclear reactions convert a fraction of the mass of interacting particles into energy, and they can release much greater amounts of energy than atomic interactions. Fission (alpha and beta decay) is the splitting of a large nucleus into smaller pieces. Fusion is the joining of two nuclei at extremely high temperature and pressure. Fusion is the process responsible for the energy of the Sun and other stars. DOK 2

SC-HS-2.3.6 Students will understand that the forces that hold the nucleus together, at nuclear distances, are usually stronger than the forces that would make it fly apart.

SC-HS-2.3.7 Students will understand that the Sun, Earth, and the rest of the solar system formed approximately 4.6 billion years ago from a nebular cloud of dust and gas.

SC-HS-2.3.8 Students will

- **compare the limitations/benefits of various techniques (i.e., radioactive dating, observing rock sequences, and comparing fossils) for estimating geological time;**
- **justify deductions about age of geologic features.**

Techniques used to estimate geological time include using radioactive dating, observing rock sequences, and comparing fossils to correlate the rock sequences at various locations. DOK 3

SC-HS-2.3.9 Students will

- **explain real-life phenomena caused by the convection of the Earth's mantle;**
- **predict the consequences of this motion on humans and other living things on the planet.**

The outward transfer of Earth's internal heat drives convection circulation in the mantle. This causes the crustal plates to move on the face of the Earth. DOK 3

SC-HS-2.3.10 Students will predict consequences of both rapid (volcanoes, earthquakes) and slow (mountain building, plate movement) earth processes from evidence/data and justify reasoning

The Earth's surface is dynamic; earthquakes and volcanic eruptions can be observed on a human time scale, but many processes, such as mountain building and plate movements, take place over hundreds of millions of years. DOK 3

UNITY AND DIVERSITY

All matter is comprised of the same basic elements, goes through the same kinds of energy transformations, and uses the same kinds of forces to move. Living organisms are no exception. Elementary students begin to observe the macroscopic features of organisms in order to make comparisons and classifications based upon likenesses and differences. Looking for patterns in the appearance and behavior of an organism leads to the notion that offspring are much like the parents, but not exactly alike. In middle school, students begin to compare, contrast, and classify the microscopic features of organisms—the cells, as well as investigate reproduction as the essential process to the continuation of all species. Expected patterns of genetic traits are predicted. Distinctions are made between learned behaviors and inherited traits. At the high school level, an in-depth study of the specialization and chemical changes occurring at the cellular level builds upon the foundational ideas developed earlier to investigate DNA and effects of alterations in DNA for an individual organism as well as for a species. Emphasis at every level should be placed upon the understanding that while every living thing is composed of similar small constituents that combine in predictable ways, it is the subtle variations within these small building blocks that account for both the likenesses and differences in form and function that create the diversity of life.

High School

Biological Science

SC-HS-3.4.1 Students will explain the role of DNA in protein synthesis.

Cells store and use information to guide their functions. The genetic information stored in DNA directs the synthesis of the thousands of proteins that each cell requires. DOK 3

SC-HS-3.4.2 Students will understand that most cell functions involve chemical reactions. Food molecules taken into cells react to provide the chemical constituents needed to synthesize other molecules. Both breakdown and synthesis are made possible by a large set of protein catalysts, called enzymes. The breakdown of some of the food molecules enables the cell to store energy in specific chemicals that are used to carry out the many functions of the cell.

SC-HS-3.4.3 Students will

- **describe cell regulation (enzyme function, diffusion, osmosis, homeostasis);**
- **predict consequences of internal/external environmental change on cell function/regulation**.

Cell functions are regulated. Regulation occurs both through changes in the activity of the functions performed by proteins and through selective expression of individual genes. This regulation allows cells to respond to their internal and external environments and to control and coordinate cell growth and division. DOK 2

SC-HS-3.4.4 Students will understand that plant cells contain chloroplasts, the site of photosynthesis. Plants and many microorganisms (e.g., Euglena) use solar energy to combine molecules of carbon dioxide and water into complex, energy-rich organic compounds and release oxygen to the environment. This process of photosynthesis provides a vital link between the Sun and energy needs of living systems.
SC-HS-3.4.5 Students will • **explain the relationship between sexual reproduction (meiosis) and the transmission of genetic information** • **draw conclusions/make predictions based on hereditary evidence/data (pedigrees, punnet squares);** Multicellular organisms, including humans, form from cells that contain two copies of each chromosome. This explains many features of heredity. Transmission of genetic information through sexual reproduction to offspring occurs when male and female gametes that contain only one representative from each chromosome pair unite. DOK 3
SC-HS-3.4.6 Students will understand that in all organisms and viruses, the instructions for specifying the characteristics are carried in nucleic acids. The chemical and structural properties of nucleic acids determine how the genetic information that underlies heredity is both encoded in genes and replicated.
SC-HS-3.4.7 Students will • **classify organisms into groups based on similarities;** • **infer relationships based on internal and external structures and chemical processes.** Biological classifications are based on how organisms are related. Organisms are classified into a hierarchy of groups and subgroups based on similarities that reflect their relationships. Species is the most fundamental unit of classification. Different species are classified by the comparison and analysis of their internal and external structures and the similarity of their chemical processes. DOK 2
SC-HS-3.4.8 Students will understand that multicellular animals have nervous systems that generate behavior. Nerve cells communicate with each other by secreting specific molecules. Specialized cells in sense organs detect light, sound, and specific chemicals enabling animals to monitor what is going on in the world around them.

BIOLOGICAL CHANGE

The only thing certain is that everything changes. Elementary students build a foundational knowledge of change by observing slow and fast changes caused by nature in their own environment, noting changes that humans and other organisms cause in their environment, and observing fossils found in or near their environment. At the middle school level, students study relationships among populations and ecosystems that contribute to the success or demise of a specific population or species. Students construct basic explanations that can account for the great diversity among organisms. The stage is set for high school students to evaluate the role natural selection plays in the diversity of species. Modern ideas of evolution provide a scientific explanation for three main sets of observable facts about life on earth: the enormous number of different life forms we see about us, the systematic similarities in anatomy and molecular chemistry we see within that diversity, and the sequence of changes in fossils found in successive layers of rock that have been formed over more than a billion years (*Science for All Americans, p. 67)*.

High School

Biological Change

SC-HS-3.5.1 Students will

- **predict the impact on species of changes to 1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, or (4) natural selection;**
- **propose solutions to real-world problems of endangered and extinct species.**

Species change over time. Biological change over time is the consequence of the interactions of (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) natural selection. The consequences of change over time provide a scientific explanation for the fossil record of ancient life forms and for the striking molecular similarities observed among the diverse species of living organisms. Changes in DNA (mutations) occur spontaneously at low rates. Some of these changes make no difference to the organism, whereas others can change cells and organisms. Only mutations in germ cells have the potential to create the variation that changes an organism's future offspring. DOK 3

SC-HS-3.5.2 Students will

- **predict the success of patterns of adaptive behaviors based on evidence/data;**
- **justify explanations of organism survival based on scientific understandings of behavior.**

The broad patterns of behavior exhibited by organisms have changed over time through natural selection to ensure reproductive success. Organisms often live in unpredictable environments, so their behavioral responses must be flexible enough to deal with uncertainty and change. Behaviors often have an adaptive logic. DOK 3

ENERGY TRANSFORMATIONS

Energy transformations are inherent in almost every system in the universe—from tangible examples at the elementary level, such as heat production in simple earth and physical systems to more abstract ideas beginning at middle school, such as those transformations involved in the growth, dying and decay of living systems. The use of models to illustrate the often invisible and abstract notions of energy transfer will aid in conceptualization, especially as students move from the macroscopic level of observation and evidence (primarily elementary school) to the microscopic interactions at the atomic level (middle and high school levels). Students in high school expand their understanding of constancy through the study of a variety of phenomena. Conceptual understanding and application of the laws of thermodynamics connect ideas about matter with energy transformations within all living, physical, and earth systems.

High School

Unifying Ideas

SC-HS-4.6.1 Students will

- **explain the relationships and connections between matter, energy, living systems, and the physical environment.**
- **give examples of conservation of matter and energy.**

As matter and energy flow through different organizational levels (e.g., cells, organs, organisms, communities) and between living systems and the physical environment, chemical elements are recombined in different ways. Each recombination results in storage and dissipation of energy into the environment as heat. Matter and energy are conserved in each change. DOK 3

SC-HS-4.6.2 Students will

- **predict wave behavior and energy transfer.**
- **apply knowledge of waves to real life phenomena/investigations.**

Waves, including sound and seismic waves, waves on water, and electromagnetic waves, can transfer energy when they interact with matter. Apparent changes in frequency can provide information about relative motion. DOK 3

SC-HS-4.6.3 Students will understand that electromagnetic waves, including radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, x-rays, and gamma rays, result when a charged object is accelerated.

SC-HS-4.6.4 Students will

- **describe the components and reservoirs involved in biogeochemical cycles (i.e., water, nitrogen, carbon dioxide, and oxygen);**
- **explain the movement of matter and energy in biogeochemical cycles and related phenomena**

The total energy of the universe is constant. Energy can change forms and/or be transferred in many ways, but it can neither be created nor destroyed. Movement of matter between reservoirs is driven by Earth's internal and external sources of energy. These movements are often accompanied by a change in physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life. DOK 3

SC-HS-4.6.5 Students will describe and explain the role of carbon-containing molecules and chemical reactions in energy transfer in living systems.

Living systems require a continuous input of energy to maintain their chemical and physical organization since the universal tendency is toward more disorganized states. The energy for life primarily derives from the Sun. Plants capture energy by absorbing light and using it to break weaker bonds in reactants (such as carbon dioxide and water) in chemical reactions that result in the formation of carbon-containing molecules. These molecules can be used to assemble larger molecules (e.g., DNA, proteins, sugars, fats). In addition, the energy released when these molecules react with oxygen to form very strong bonds can be used as sources of energy for life processes. DOK 3

SC-HS-4.6.6 Students will understand that heat is the manifestation of the random motion and vibrations of atoms

SC-HS-4.6.7 Students will

- **explain real world applications of energy using information/data.**
- **evaluate explanations of mechanical systems using current scientific knowledge about energy.**

The universe becomes less orderly and less organized over time. Thus, the overall effect is that the energy is spread out uniformly. For example, in the operation of mechanical systems, the useful energy output is always less than the energy input; the difference appears as heat. DOK 2

SC-HS-4.6.8 Students will

- **describe the connections between the functioning of the Earth system and its sources of energy (internal and external).**
- **predict the consequences of changes to any component of the Earth system.**

Earth systems have sources of energy that are internal and external to the Earth. The Sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational energy from Earth's original formation. DOK 3

SC-HS-4.6.9 Students will

- **explain the cause and effect relationship between global climate and weather patterns and energy transfer (cloud cover, location of mountain ranges, oceans);**
- **predict the consequences of changes to the global climate and weather patterns.**

Global climate is determined by energy transfer from the Sun at and near Earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover and the Earth's rotation and static conditions such as the position of mountain ranges and oceans. DOK 3

SC-HS-4.6.10 Students will

- **identify the components and mechanisms of energy stored and released from food molecules (photosynthesis and respiration).**
- **apply information to real-world situations.**

Energy is released when the bonds of food molecules are broken and new compounds with lower energy bonds are formed. Cells usually store this energy temporarily in the phosphate bonds of ATP. During the process of cellular respiration, some energy is lost as heat. DOK 3

INTERDEPENDENCE

It is not difficult for students to grasp the general notion that species depend on one another and on the environment for survival. But their awareness must be supported by knowledge of the kinds of relationships that exist among organisms, the kinds of physical conditions that organisms must cope with, the kinds of environments created by the interaction of organisms with one another and their physical surroundings, and the complexity of such systems. Elementary learners need to become acquainted with ecosystems that are easily observable to them by beginning to study the habitats of many types of local organisms. Students begin to investigate the survival needs of different organisms and how the environment affects optimum conditions for survival. In middle school, students should be guided from specific examples of the interdependency of organisms to a more systematic view of the interactions that take place among organisms and their surroundings. At the high school level, the concept of an ecosystem should bring coherence to the complex array of relationships among organisms and environments that students have encountered. Students growing understanding of systems in general will reinforce the concept of ecosystems. Stability and change in ecosystems can be considered in terms of variables such as population size, number and kinds of species, productivity, and the effect of human intervention. (*adapted from Benchmarks for Science Literacy)*

High School

Unifying Ideas

SC-HS-4.7.1 Students will

- **analyze relationships and interactions among organisms in ecosystems.**
- **predict the effects on other organisms of changes to one or more components of the ecosystem.**

Organisms both cooperate and compete in ecosystems. Often changes in one component of an ecosystem will have effects on the entire system that are difficult to predict. The interrelationships and interdependencies of these organisms may generate ecosystems that are stable for hundreds or thousands of years. DOK 3

SC-HS-4.7.2 Students will

- **evaluate proposed solutions from multiple perspectives to environmental problems caused by human interaction;**
- **justify positions using evidence/data.**

Human beings live within the world's ecosystems. Human activities can deliberately or inadvertently alter the dynamics in ecosystems. These activities can threaten current and future global stability and, if not addressed, ecosystems can be irreversibly affected. DOK 3

SC-HS-4.7.3 Students will • **predict the consequences of changes to any component (i.e., atmosphere, solid Earth, oceans, living things) of the Earth System;** • **propose justifiable solutions to global problems.** Interactions among the solid Earth, the oceans, the atmosphere, and living things have resulted in the ongoing development of a changing Earth system. DOK 3
SC-HS-4.7.4 Students will understand that evidence for one-celled forms of life, the bacteria, extends back more than 3.5 billion years. The changes in life over time caused dramatic changes in the composition of the Earth's atmosphere, which did not originally contain oxygen.
SC-HS-4.7.5 Students will • **predict the consequences of changes in resources to a population;** • **select or defend solutions to real-world problems of population control.** Living organisms have the capacity to produce populations of infinite size. However, behaviors, environments, and resources influence the size of populations. Models (e.g., mathematical, physical, conceptual) can be used to make predictions about changes in the size or rate of growth of a population. DOK 3